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Morphometric analysis of a fresh simple crater on the Moon

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Abstract. In this research we are proposing an innovative method to determine and quantify the morphology of a simple fresh impact crater. Linné is a well preserved impact crater of 2.2 km in diameter, located at 27.7^{o}N 11.8^{o}E, near the western edge of Mare Serenitatis on the Moon. The crater was photographed by the Lunar Orbiter and the Apollo space missions. Its particular morphology may place Linné as the most striking example of small fresh simple crater. Morphometric analysis, conducted on recent high resolution DTM from LROC (NASA), quantitatively confirmed the pristine morphology of the crater, revealing a clear inner layering which highlight a sequence of lava emplacement events.

Key words. Moon fresh craters

1. Introduction

Impact craters are the most widespread landform on rocky bodies surfaces of the Solar System (Wilhelms 1987). Their morphology classically depends on the interaction between gravity and target strength under dynamical loading. In addition, post-impact modification processes, as for instance crater degradation, might deeply affect the observed structure. Over the years, morphological and degradation classification of simple impact craters has been performed only through visual interpretation. Hence this method is stricken by a subjective interpretation based on simple images analysis. The most accepted classification of simple craters degradation is proposed in "Lunar and Planetary Laboratory" catalog (Arthur et al. 1963). He subdivided impact craters in four classes of degradation, ranging from class 1, for the freshest craters, to the class 4 for the most ancient ones. However this classification is based on visual interpretation that is obviously affected by a high degree of subjectivity. In this research we are proposing an innovative method to determine and quantify the morphology of simple impact craters. Morphometric analysis indeed has twofold benefits as the topographic based survey and the quantitative approach of investigation, supplying an objective analysis.

2. Morphometric analysis

The data, from recent remote sensing space missions, start to provide high resolution DTMs (digital terrain models). This detailed topography enables us to characterize and quantify the geomorphology of significant sec-

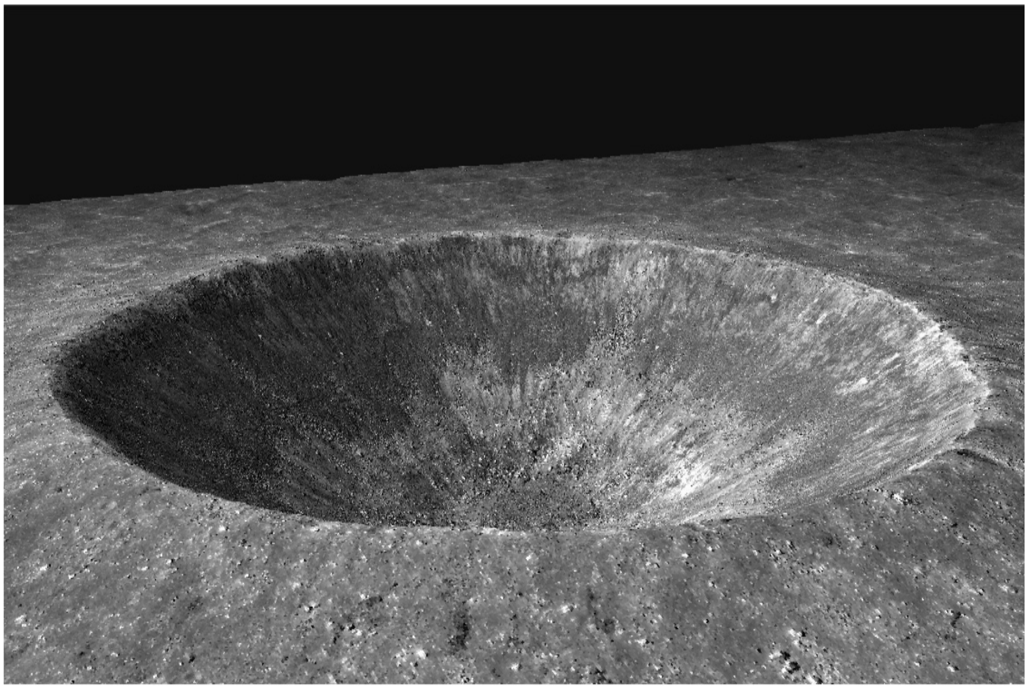

Fig. 1. 3D visualization of Linné crater.

tors of craters, in function of the degradation rate.

Morphometric analysis enables us to quantify different morphological characters of landforms, allowing the calculation of morphometric variables statistics. Morphometric analyses on planetary surfaces are usually conducted trough the analysis of 2D topographic profiles (Fassett and Thompson 2014), but areal 3D studies on high resolution DTMs are normally favored by earth geomorphologists since in this way a much more robust statistic is guaranteed. Moreover, this distributed analysis allow a better understanding of the real landforms charachteristics (i.e. areal extension, continuity, precise boundary definition, etc.). In this work, we apply for the first time an areal approach to obtain morphometric variables of a planetary surface. In particular, we focus on morphometric variables such has slope and curvatures. The first derivative of the altimetry is the slope, useful to detect the inner wall of craters. The second derivatives are curvatures that are calculated along different planes: profile curvature is calculated along the maximum slope plane and plan curvature along the horizontal plane. Curvatures are useful to detect rim area, rim crest (for fresh craters), outer wall and morphologic changes within the inner wall. In order to reduce DTM noises and errors we applied a multi-scalar approach (Wood 1996), testing different ranges of kernel sizes (the dimension of the pixel matrix on which variables are calculated). This enabled us to evaluate the best window size for extracting the morphometric variables from the DTM and isolate the morphologies of interest. Land Serf was used to statistically assess the maximum expression of profile curvature at different kernel sizes. In this way we obtained the best kernel size to morphometrically characterize each specific sector of the crater (i.e. rim, inner and outer slope, floor).

3. Case of study: Linné crater

Simple crater morphology can be best retrieved from fresh pristine impact structures. In this

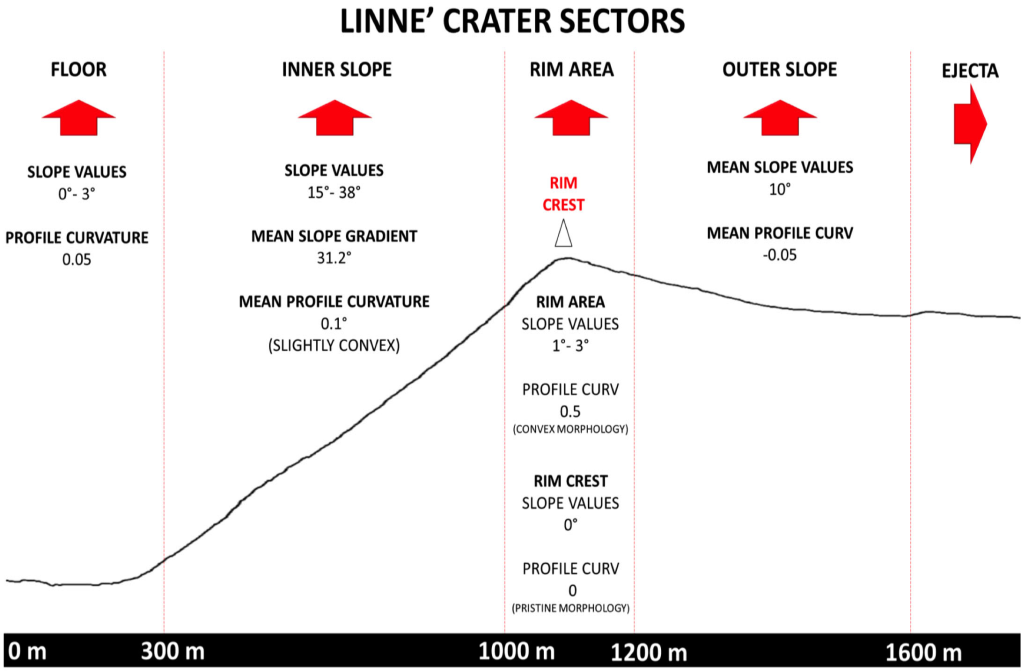

Fig. 2. Morphologic sectors of Linné crater.

regard Linné (Fig.1) is one of the best preserved impact crater on the Moon, displaying a pristine morphology appearing as an inverted truncated cone (Garvin et al. 2011). Linné is situated near the western edge of mare Serenitatis, a basalt basin located on the nearside of the Moon. For this case of study we used a DTM derived from NASA LROC (Lunar Reconnaissance Orbiter Camera) NAC (Narrow Angle Camera), with a resolution ranging from 0.5 to 2m/pixel with a cell size of 2m. For this analysis we calculated every windows size ranging from 6 m to 198 m on the Linné DTM, introducing a progressive smoothing of landforms. In particular, the more favorable windows size resulted to be the 66 m one. In order to better understand the morphological expression of homogeneous areas, we had to conceptualize the crater, subdividing it into different sectors: rim, floor, inner and outer wall (Fig.2). Morphometric variables have been used to create masks for separating the different sectors of the crater. In particular, slope was useful to detect the inner wall and the floor, and profile curvature to detect the rim crest. All pixels morphometric values pertaining to each sector of the crater were than extracted retrieving the morphometric signature of Linné on each distinguished sector. Finally, we applied a classification on slope and curvature, useful to detect and enhance even bland morphologic changes. More in detail this classification underlined the presence of 3 morphologic layers, as continuous convex boundaries, within the inner wall of Linné crater.

4. Morphometric signature of Linné and inner wall layering

Linné crater covers an area of about 3.8 km^2: within the rim being the inner wall (3.5 km^2) representative of the 92 percent of the total. The mean slope gradient of inner wall is 31.2°, consistently with the lunar regolith angle of repose (31°) (Nickerson et al. 2011), whereas the mean profile curvature is 0.1, slightly convex (> 0). According to our analysis the Linn floor presents a mean slope gradient of 0°-3° with a

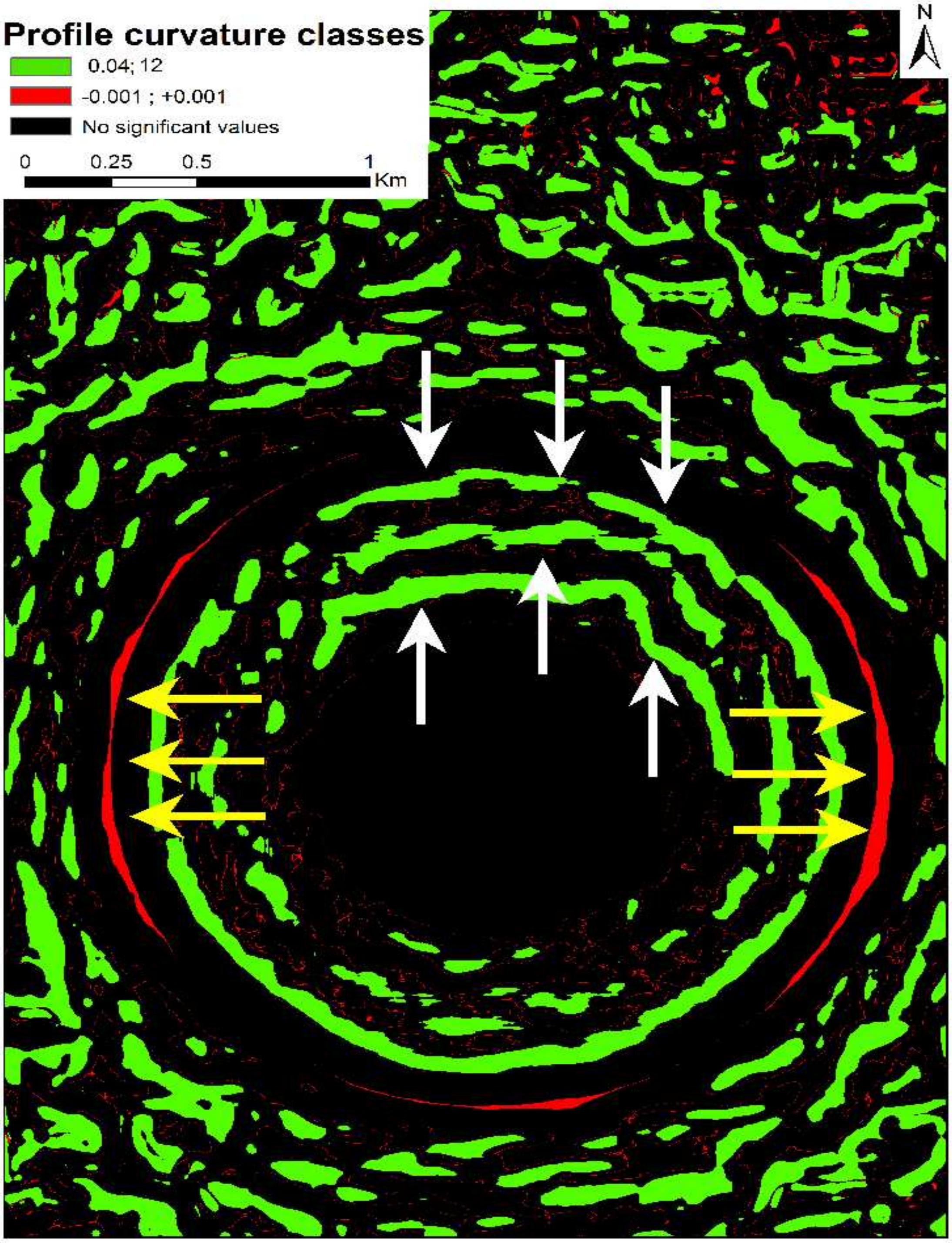

Fig. 3. Classification of profile curvature. Green boundaries are the evidence of morphological steps. Red boundary is the rim crest.

profile curvature of 0.05°; these values are typical of a flat floor. the rim sector is characterize by a mean profile curvature of 0.5 (convex morphology), with a slim top area with about 0 of profile curvature, revealing the presence of a pristine crest. For these particular morphometric characteristics Linn can be classify as a fresh crater, not eroded by degradation processes. On the external scarp the mean slope gradient is about 10° and the profile curvature is negative (-0.05), defining a slightly concave morphology. We finally discovered 3 clear cut boundaries within the inner scarp of the crater, at a depth of about +50, -100 and -200 m from lunar mean surface, that are expression of a convex morphology, as shown in Fig.3. These features are characterized by positive profile curvature values. Convex morphologies within craters walls may be related to different causes such as post-impact or gravitational landslides, but these processes typically present irregular morphologies. Differently in our case the continuity of the convex scarps within the inner wall suggest a transition between overlapping geological units (likely lava flows interleaved by regolith or volcanic ashes) in mare Serenitatis.

5. Conclusions

Our work shows the potential of morphometric analysis in detecting and quantifying the geomorphology of impact craters. In this specific case of study, we have used morphometric analysis to derive and measure the morphological expression of the different sectors of the Linné crater, and to infer the stratigraphy at the impact site revealing subsequent emplacements of thin lava flows within mare Serenitatis. The quantification and classification of morphometric variables described in this research, may be useful also for semi-automatic detection and characterization of the degradation classes of simple craters. Potentially in the future this could be a helpful tool for geological mapping of planetary surfaces. As far as the stratigraphic application is concerned, morphometric analysis can be applied to retrieve stratigraphic sections within different simple craters, allowing a stratigraphic correlation among different lava layers within lunar maria.

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